EVALUATION OF DISASTER MITIGATION SYSTEM AGAINST LAHAR FLOW OF PUTIH RIVER, MT. MERAPI AREA

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ABSTRACT

Merapi mount lies in the border of Yogyakarta and Central Java province. It frequently produces lava sediment deposit in the upper part of the mount, or is called as lava dome. During the rain, the sediment can cause secondary disaster in form of lahar flood, which is potential to produce casualties, especially to the miners working along the river. Kali Putih, that is located in Magelang regency, is the area that undergoes frequents lahar flood that is 125 times in the period of 1931-1996. Meanwhile, there are 5,076 sand miners there. Therefore, it needs an evaluation toward the existing mitigation system that is related to the safety of sand miners.

The evaluation is done toward structural mitigation system (Sabo Dam) and non-structural one (e.g. early warning, counseling, and evacuation system). Structural mitigation system is evaluated by comparing the availability of control volume of Sabo Dam to the sediment load during lahar flood, and comparing the travel time of the lahar flood with and without Sabo Dam. Non-structural mitigation system is evaluated by testing the accuracy of the lahar flood estimation chart, and by identifying early warning equipment system installed in field. Interview is also conducted with the miners to see their perception and opinions toward the mitigation.

Result of the evaluation shows that the existing early warning system does not produce sufficient time for the sand miners to save themselves. The proposed solution is to divide sand mine area in Putih River into 3 zones, each zone has different procedure of the early warning and evacuation. This is arranged to avoid casualties to the sand miners.

Keywords: Lahar flood, sand miners, early warning.

1 INTRODUCTION

Merapi volcano located ± 2,968 m above sea level, in Yogyakarta and Central Java is included to active volcanoes. It has been erupted during 1902-2001 for 26 times. Besides the primary disaster including volcanic ash and lava, lahar activity on Merapi also has incurred lava dome. The forming of lava dome is 1 million m^3 / year in speed, yet the highly increasing activity happened in 1984 that reached 500,000 m^3 / day. On rainy season, lava dome or eruption material deposits collapse and triggered by rainfall, then turn into lahar flood which may cause many victims and damages toward the traversed area. It is known as secondary disaster of Merapi eruption.

Putih River which is ± 23 km in length and flows from Merapi volcano has experienced numerous lahar floods, 125 times during 1931-1996. Recently, there are many sand mining activities involved with approximately 5,076 people located in 10 different sites in which of closest area is 5.3 km from Merapi peak as seen at Figure 1.

This research is aimed to evaluate the capacity of disaster mitigation system, particularly in giving sufficient evacuation time for sand miners at Putih Rivers evacuating themselves. The research result is expected to be a consideration for stakeholders in determining the forthcoming disaster mitigation system so that it will be in accordance with the needs and the desires of the people (bottom up), particularly in sand mining along Putih River. To cope with the broad area, some limitations are used as follows:

a) Potential source of lahar flood used in analysis is material deposits from formerly eruption.
b) Evaluations towards structural mitigation (Sabo Dam structure) and nonstructural mitigation, i.e. early warning system, communication building, evacuation, and dissemination are conducted.
c) The function of structural and nonstructural mitigation system is deemed effective if it can control lahar flood and give enough time for sand miners evacuating themselves.

2 HYPOTHESIS

A hypothesis that can be drawn from available literature review and theoretical approach is that the existing nonstructural mitigation system has not completely protected sand miners working along river channel from lahar flood threat since it is intended to protect people living at downstream area only in which prone to lahar flood.

3 RESEARCH METHODOLOGY

This research is conducted according to the flow chart provided at Figure 2. It is started with secondary data collection regarding to the existing structural and nonstructural mitigation system, then continued to primary data collection by questionnaire method or interviewing sand miners. In order to know the capacity of existing mitigation system, some evaluations are necessary to do.

3.1 Evaluation of structural mitigation system:

a) Comparing regulating storage of the existing Sabo dam to maximum sediment volume carried by one occurrence of lahar flood for a return period of 100 year to estimate the capacity of Sabo Dam in controlling lahar flood.

b) Comparing flood time of concentration to the sand mining location for full storage capacity condition of Sabo Dam and no Sabo Dam condition

c) Conducting survey or interviewing sand miners in order to know their opinions towards existing structural mitigation system and their expectations afterwards.

3.2 Nonstructural mitigation system:

a) Accuracy data testing was conducted based on lahar flood prediction graph.

b) Field identification and secondary data processing against existing condition of early warning system supporting device.

c) Conducting a survey or interviewing sand miners for gathering information and opinions concerning to the existing nonstructural mitigation system and their expectations for the future mitigation system.

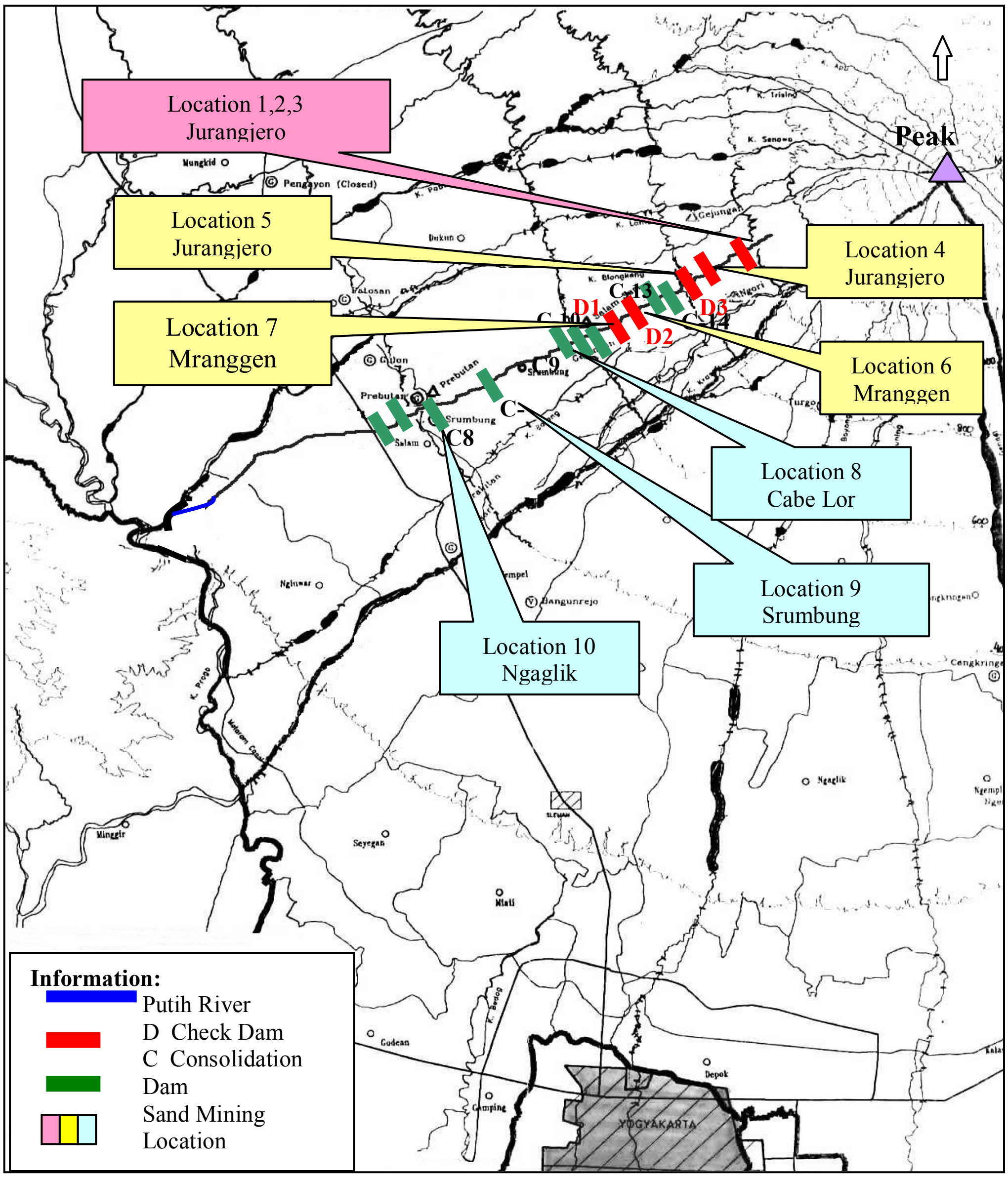

Figure 1. Research Location in Putih River.

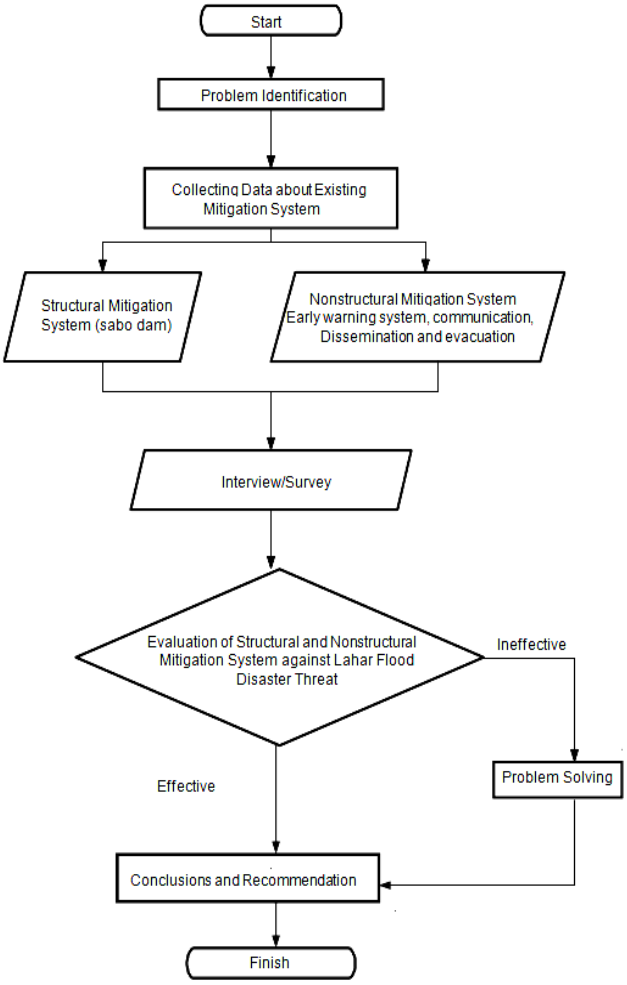

Figure 2. Research flow chart.

4 RESULTS AND ANALYSIS

4.1 Structural Mitigation System

Structural mitigation system that has been largely implemented in an attempt of secondary disaster prevention is Sabo Dam included check dam and consolidation dam. Sabo Dam is capable to store and control sediment and boulders swept off lahar flood and overwhelming downstream (see Figure 3). The field observation, secondary data processing, and the interview/survey results toward sand miners concerning to the implementation structural mitigation system are summarized below:

a) Regulating storage capacity of Sabo Dam in Putih River, V_c which amounts 405.733 m^3 as shown in Table 1 is more than estimated maximum sediment transport for 100 year of return period, V_s = 216.624 m so that Sabo Dam is deemed to be able to control lahar flood. This deposited sediment volume can be mined within only 21 days if it is assumed that sand mining productivity is 10,116 m^3/day.

b) According to the estimated concentration time (see Figure 4), Sabo Dam with full storage capacity is capable to retard concentration time of lahar flood yet it does not give much significant time.

c) Sabo Dam in Putih River functions well in controlling lahar flood as clarified by sand miners.

From the explanations above, the existing structural mitigation system is considered effective.

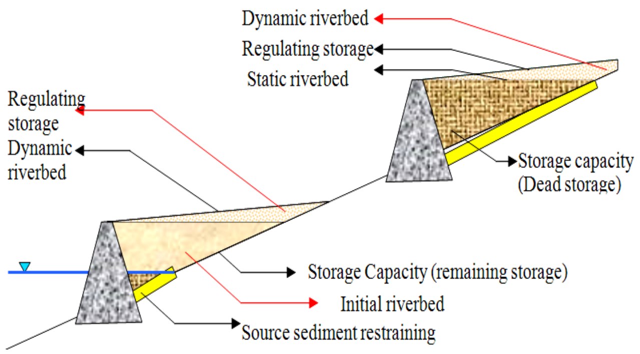

Figure 3. Sediment type and control in Sabo Dam (Yachiyo Eng.Co.Ltd, 2001).

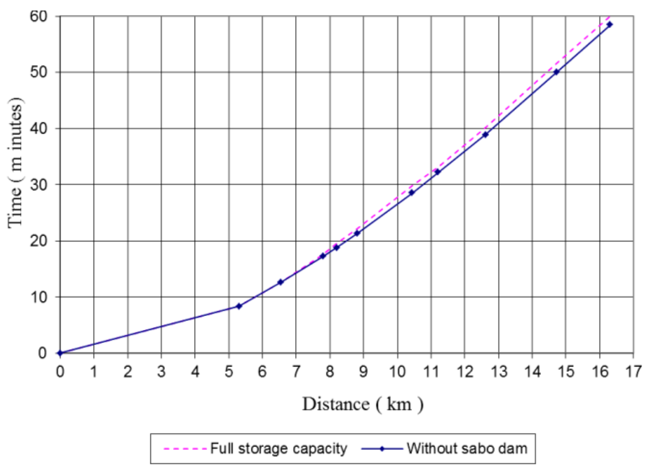

Figure 4. Comparison between time of concentration of lahar flood and sand mining location along Putih River.

4.2 Nonstructural Mitigation System

Methods and devices used in nonstructural mitigation system to anticipate lahar flood disaster are as follows:

4.2.1 Lahar Flood Estimation Method

Lahar flood estimation was developed by Sabo Office and Sabo Training Centre (STC) from prior study about correlation between lahar flood occurrence and rainfall intensity in Putih River. Rainfall data during

Table 1. Technical data of Sabo Dam structure in Putih River

Height, H (m)	Length, L (m)	Distance from prior structure, D (m)	River bed slope			Sediment storage length		Sediment capacity	
			Initial, I_o (%)	Static, Is (%)	Dynamic, Id (%)	Static, Ls (m)	Dynamic, Ld (m)	Storage volume, Vs (m3)	Control volume (m^3)
8	83	-	8.07	4.03	5.38	148.79	223.19	34,371	17,185
13.5	164	400	8.07	4.03	5.38	285.18	427.77	259,089	104,311
9	45	620	6.89	3.44	4.59	203.25	304.88	27,744	13,872
5.5	70	350	6.89	3.44	4.59	101.63	152.44	11,382	5,691
4	61.5	620	5.88	2.94	3.92	68.00	102.01	3,774	1,887
11.1	220	650	5.88	2.94	3.92	309.42	464.13	301,281	150,640
5	55	771	5.53	2.76	3.68	108.60	162.90	7,982	3,991
6.5	85	450	5.53	2.76	3.68	162.90	244.34	28,955	14,477
2.3	96.5	450	5.53	2.76	3.68	10.86	16.29	0.0	0.0
5	105	500	5.39	2.69	3.59	111.36	167.04	0.0	0.0
6.5	89	2120	4.60	2.30	3.07	195.65	293.48	36,538	18,269
4	52	1580	4.60	2.30	3.07	86.96	130.43	0.0	0.0
7.5	26	480	2.10	1.05	1.40	523.81	785.71	26,400	16,814
9.5	43.5	1250	1.80	0.90	1.20	833.33	1250.00	117,188	58,594
							Total	854,703	405,733

1985-1989 is collected for creating critical line. Soil moisture due to antecedent rainfall is accounted. A critical line divides graph into two areas, safe and hazardous area. Safe area is above the critical line, while hazardous is below the critical line.

A warning indicator against lahar flood occurrence uses Warning Line (WL) calculated from maximum rainfall data at two hours before flood comes, and Evacuation line (EL) from rainfall intensity data at 1 hour before flood comes in the same period.

Accuracy testing towards prediction graph of lahar flood occurrence is conducted by including rainfall intensity data on November 1999 and 2000 recorded on rainfall station of Gunung Maron.

In order to obtain antecedent rainfall (a week before), the following formula is used:

$$RWA = \sum_{t=1}^{t=7} \alpha_t . d_t \tag{1}$$

where RWA is antecedent rainfall (mm), α represents reduction coefficient = $0.5^{(t/T)}$, t time (day), d_t represents 24-hours rainfall on day-t, $T = 0.5$ (day).

Plotted data (Figure 5) shows that there are 2 rainfall occurrences which may cause lahar flood on November 1999, 4 rainfall occurrences on November 2000. These rainfall occurrences exceed Warning Line (WL) and Evacuation Line (EL), but main station in Sabo Office did not record lahar flood history in those years. The interview which was carried out on this research gave information that on November 1999 (no date information), there was a lahar flood drowning 3 trucks and 1 backhoe due to no given warning. There was no information gained regarding to the predicted lahar flood on November 2000. These results indicate that lahar flood prediction has not been accurate if it only uses data plotted on the graph.

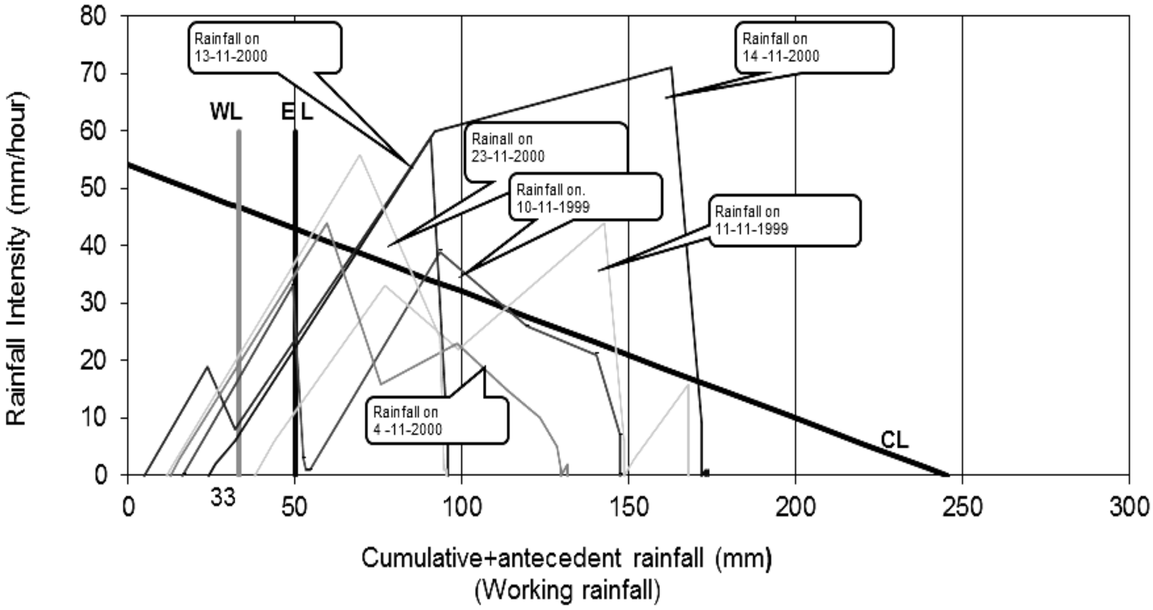

Figure 5. Flood prediction graph.

4.2.2 Early Warning Supporting Devices

Supporting devices of early warning system installed on the field are as follows:

a) Telemetry system. It is used for sending data using radio waves. By this device, the measured data can be known, processed, displayed, and printed at main station (Sabo Office) as soon as possible.
b) Wire sensor. It comprises TIV wire type 0.8-2 cores installed cross over check dam PU-D5 in Jurangjero, so that if only it is broken due to flood, it will send a signal to main station through telemetry.
c) Vibration sensor. It generates electrical oscillation which will react if there is a vibration induced by lahar flood through the ground oscillating a spring inside vibration sensor and automatically send signal to the main station. It is buried on the ground upstream of check dam PU-D5 in Jurangjero.
d) Ultrasonic water level. It applies transducer as main sensor installed above water level perpendicularly so that it will safe from lahar flood (Sumaryon and Sukatja, 2002). It is installed in PU-D5 and PU-D1 Check Dam.
e) Radar rainfall recorded. It can give information about location, intensity, distribution, and current movement of the rainfall so that it can predict disastrous area in which lahar flood may occur. The most important function of this radar is to give rainfall intensity information within wide range area (maximum area is 80 x 60 km^2) that can be displayed on the monitor every 5 minutes without being disrupted by Merapi volcano activity.
f) Automatic rainfall recorder. The devices located on Gunung Maron and Mranggen are used for gaining rainfall intensity as a part of early warning system. It is programmed to be able to send the data every 10 minutes when rainfall occurs and every 1 hour if there is no rainfall.

From both field identification and interview, some supporting devices are admitted to be broken, i.e. rainfall radar, wire sensor, and vibration sensor. The other devices which still work properly are telemetry system, automatic rainfall recorder, and ultrasonic water level. On this condition, associated with limited communication range, early warning system capacity in giving information and prediction towards sand miners may become less.

4.2.3 Interview with the sand miners

Sand miners thought that nonstructural mitigation systems, particularly early warning system and communication have not provided sufficient time for evacuation, especially for the people worked in sand mining along River Putih upstream.

From the above explanation, the existing nonstructural mitigation system has been ineffective so that reparation and improvement should be done in order to be able to satisfy the needs and the desires of sand miners (bottom-up). The followings recommendations are proposed to improve nonstructural mitigation system:

Short term program (within 1 year)

a) Dividing sand mining area into three zones with specific management as shown in Table 2 and Figure 6. Mitigation management is arranged referring to life and properties prevention.
b) Some supporting infrastructures are important to prepare in order to make an effective zone division:
   – Repairing or changing the broken early warning devices.
   – Installing repeater and wire sensor provided with alarm on the upstream of Putih River, and also providing HT with sound locking facility.
   – Building public surveillance post at sand mining location comprising *satlinmas* (social protection unit) of the village, sand mining organization (GORO). It monitors early warning system, manages sand miners whenever the flood comes, and their activity in order to keep Sabo Dam structure and early warning devices from destruction.
   – Training and enhancing coordination among every unit concerned to lahar flood disaster. Conducting dissemination for sand miners/truck driver/system operator

Long term program (3 years)

a) Further research is required to develop a formula or correlation between rainfall intensity and lahar flood over Putih River.
b) SIPD (Regional sand mining admission) giving should be firmer. It should contain regulation about sands/gravels volume in detail which permits to be mined and a mining threshold point to ease the sand mining control.

Table 2. Early warning system operational in sand mining zone along Putih River

No.	Activity/Instruction	ZONE - 1	ZONE - 2	ZONE - 3
	Information Route	Sand mining locations 1,2,3 in Jurangjero Flood time of concentration < 20 minutes	Sand mining locations 4,5,6,7 in Jurangjero and Mranggen Flood time of concentration 20-40 minutes	Sand mining locations 8,9,10 in Cabe Lor, Srumbung, Ngaglik Flood time of concentration 40-60 minutes
1	*WASPADA* (Sand miners may work, while they manage position of truck that is ready to move)	Cumulative rainfall: 33 mm (Working rainfall).	Cumulative rainfall: 50 mm (Working rainfall).	Lahar movement has reached PU D5 Check Dam.
	Normal Communication Route	BSB -SPK -SPC -SPD/KPG -PP1 -PPS	BSB - SPK - SPC - SPD/KPG - PP 2,3 - PPS	BSB - SPK - SPC - SPD – PPS or PP1 - SPD - PPS
2	*BERKUMPUL* (Sand miners and truck gathers at the safe area on the main road)	Cumulative rainfall: 50 mm (Working rainfall).	Lahar flood occurs in the upstream of Putih River / wire sensor installed on the first mining spot is broken.	Lahar movement has reached PU D1 Check Dam.
	Emergency Communication Route	BSB - SPD/KPG - PP1 - PPS	BSB - SPD/KPG - PP 2,3 - PPS or PP1 - PP 2,3 - PPS	BSB - SPD – PPS or PP3 - SPD - PPS
3	*EVAKUASI* (surveillance post officer coordinates evacuation process to TPS-1)	Lahar flood has been endangered or approached protection dike (officer visual monitoring).	Lahar flood has been endangered or approached protection dike (officer visual monitoring).	Lahar flood has been endangered or reached PU-C10 Dam at Ngepos (*satlinmas* PBP visual monitoring).
		PP1 - PPS	PP 2,3 - PPS	SPD - PPS

Information:

BSB : Sabo Office
SPD : *Satlinmas* PBP (Village)
PPS : Sand miners
KPG : Central Office of GORO
SPK : *Satlak* PBP of Magelang City
SPC : PBP Operation unit of Srumbung Sub district
PP 1, 2, 3 : Surveillance post officer at location of 1, 2, 3

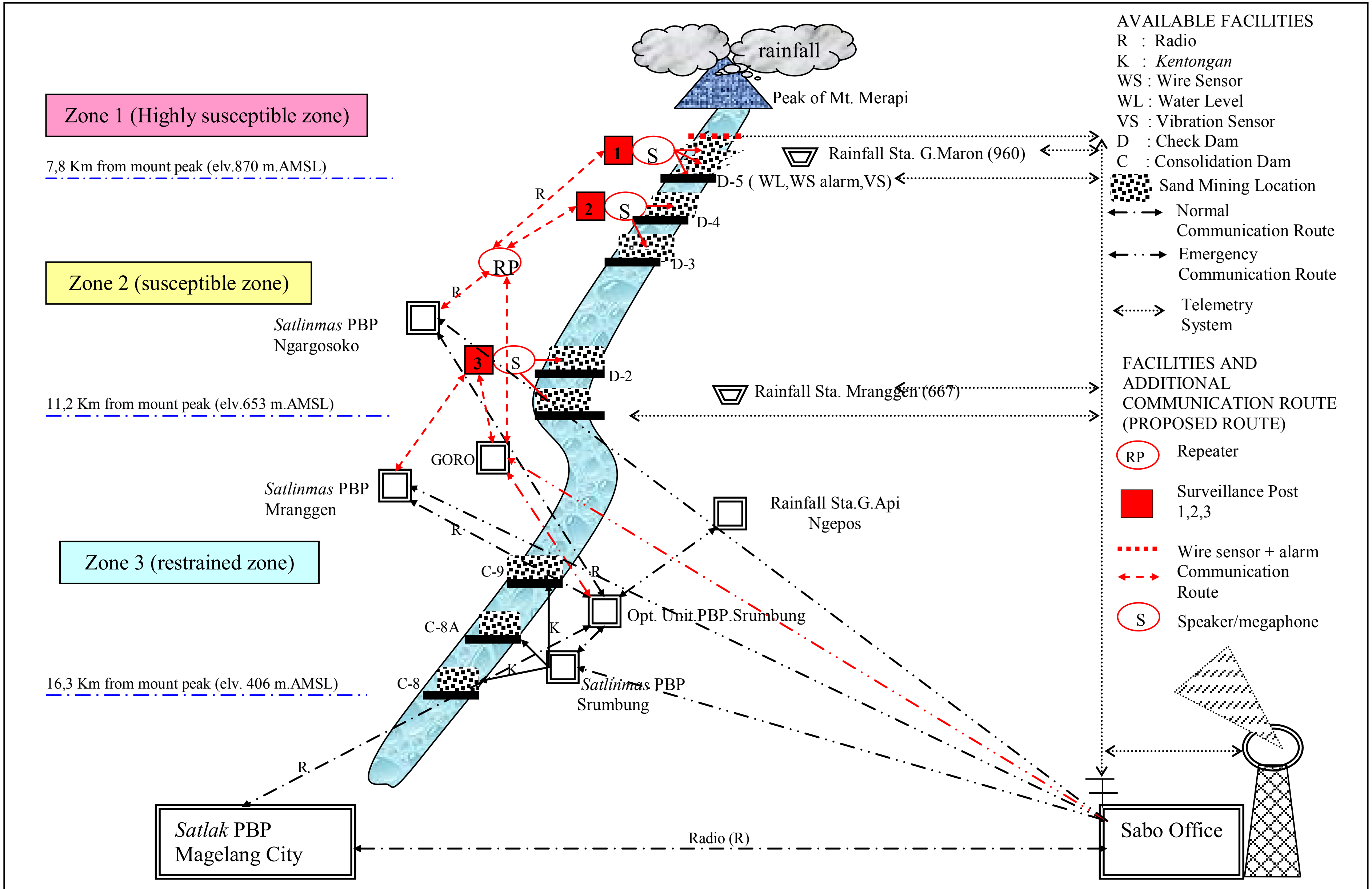

Figure 6. Sketch of early warning system operational in Putih River (Proposed).

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Some conclusions that can be drawn from the results are as follow:

a) Structural managements through Check Dam and Consolidation Dam in Putih River have functioned effectively since structural mitigation can restrain lahar flood and retard concentration time of lahar flood. The existing nonstructural mitigation system is still ineffective since information about early warning system for sand miners along Putih River has not been available yet which is caused by:

   – Lahar flood prediction method has lack of accuracy.
   – Lahar flood occurrence can be predicted by Sabo Office only after traversing three sand mining locations located in the upstream river.
   – There are some supporting devices of early warning system, such as rainfall radar, wire sensor, and vibration sensor which are broken so that the early warning system cannot monitor lahar movement.
   – The use of *kenthongan* (traditional communication device) in announcing lahar flood warning is only effective to be applied at the sand mining located near the houses. Communication device used for the sand mining located far away from the houses is HT (through radio transmitter). However, the communication range is limited, and the sand miners rarely have HT.

b) GORO (Sand Miners Organization) has an important role in mining activity so that the involvement of this organization is required in lahar flood mitigation and restructuration of mining location.

c) Due to many sand mining activities involved, sand miners working along Putih River should have priority in mitigation system since they are highly prone to lahar flood disaster. Meanwhile, the existing mitigation system used to protect people living in the downstream only. It means that the forthcoming nonstructural mitigation system should reckon the real condition in the field.

5.2 Recommendations

In order to make an effective nonstructural mitigation system based on the desires of sand miners (bottom-up), there are some recommendations which may be applied:

a) Sand mining area is divided into three zones according to the flood concentration time, i.e. highly susceptible zone (includes mining location 1, 2, 3), susceptible zone (includes location 4, 5, 6, and 7), and restrained zone at the downstream of Putih River (location 8, 9, and 10). Management of disaster mitigation system is arranged by referring to the life and properties prevention and implemented to early warning system.

b) Building a public surveillance post at the location of sand mining comprising *satlinmas* PBP (social protection unit) of the village and sand mining organization (GORO) is necessary to monitor, to give some instructions when flood attacks, and control the mining activities for avoiding the destruction of Sabo Dam structure and early warning devices.

c) Primary disaster can be prevented by early warning system that gives information about the status of Merapi volcano, i.e. *Siaga Merapi* and *Awas Merapi* against the sand mining activities.

d) Early warning device is apparently needed changing and repairing. Some devices are broken, for instance rainfall radar, wire sensor and vibration sensor. It is required to install the new wire sensor provided with alarm at the upstream of the first sand mining location.

e) Radio communication (HT) supported by sound locking facility and a repeater should be provided for expanding communication range.

f) Training, dissemination, and enhancing coordination among every unit concerned to lahar flood disaster that involves sand miners/truck driver/system operator is necessary in order to gain the similar perception or understanding against disaster.

g) Further research is required to develop reliable formula that correlates rainfall and lahar flood occurrence in Merapi volcano by involving relevance experts.

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